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Elementary Teachers' Reflections on their use of Digital Instructional Resources in Four Educational Contexts: Belgium, Finland, Sweden, and U.S.

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Elementary Teachers' Reflections on their use of Digital Instructional Resources in Four Educational Contexts: Belgium, Finland, Sweden, and U.S.

We examine teachers' reflections on incorporating digital instructional resources (DIRs) into their mathematics teaching. We analyze qualitative interviews with 39 elementary school teachers from four educational contexts: Belgium, Finland, Sweden, and the U.S., using a framework proposed by Pepin et al. (2017) to consider opportunities for DIRs to shift elements of teaching and learning in potentially transformative ways. Teachers described three major domains of teaching practice where they used DIRs: a) class instruction, b) student practice, and c) professional participation. We found that teachers readily used DIRs during class instruction and to support student practice, guided by their existing instructional goals, which were shaped in part by education structures in the context. Few teachers incorporated DIRs in ways that transformed typical learning spaces. We also found that DIRs impacted several aspects of teachers' professional practices, including professional learning and collaboration. In particular, participation in social media and resource sharing altered the nature of and ways teachers participated in their own professional learning. We assert that efforts to use DIRs to stimulate change need to begin with an understanding of teachers' current practices and use our findings to identify three potential levers that might support movement toward change.

1. Introduction

The first two decades of the 21st Century has seen a rapid proliferation of digital instructional resources available from curriculum publishers, online vendors, universities, and other organizations. Many developers and educators see the potential for digital resources to "influence, afford or . . . transform particular educational processes and practices (Pepin, Choppin, Ruthven, & Sinclair, 2017, p. 645). This notion is informed by a growing body of research and exemplars from around the world; in mathematics classrooms where teachers have access to fully digital curricula and networked tools substantial shifts in the types of tasks students engage in and patterns of interaction can be realized (e.g., Clark-Wilson, 2010; Daro, 2016; Edson, 2017; Yerushalmy, 2006; 2013).

While research on teachers' use of print materials is well developed, research on teachers' use of digital resources is still developing (Pepin et al., 2017). In light of the growing availability of digital resources and the need for greater understanding of their impact on teaching and learning, scholars have called for research on teachers' perspectives and practices in this domain (Healy & Lagrange, 2010; Remillard, 2016). The current study addresses this call from a cross-contextual perspective. We examine how 39 elementary school teachers in

Belgium, Finland, Sweden, and the U.S. describe their use of digital instructional resources (DIRs) in their mathematics teaching. The following questions guide our analysis:

1. How do elementary teachers in four educational contexts describe their uses of digital resources in their mathematics instruction and the reasons underlying them?
2. What context-specific educational practices and perspectives are revealed through teachers' reflections on using DIRs?
3. What opportunities for transformation of teaching and learning are made possible through teachers' use of DIRs?

Our aim is to understand a range of teachers' current practices and priorities with respect to digital resources as a starting place to consider the potential for and meaning of transformation. This approach complements research that starts with particular digital resources and considers how teachers use them.

2. Background and Framing Concepts

Our research builds on existing frameworks for studying teachers' use of print curriculum resources (e.g., Gueudet & Trouche, 2009; Remillard, 2005) and a framework oriented toward the design and affordances of digital curriculum resources (Pepin et al., 2017). As mentioned, our study takes a cross-contextual perspective, which assumes that instructional resources and educational trends that cross national boundaries are likely understood and taken up differently in each context (Stigler & Hiebert, 1999; Tobin et al. 2009). We use the term digital instructional resources (DIRs) to refer to a broad array of digital applications, tools, and media for or appropriated to support mathematics instruction (Gueudet & Trouche, 2009). These resources include digital textbooks, slideshows or videos, dynamic software students interact with, static images or tasks in digital formats, as well as resources that support communication around mathematics teaching and learning. Our use of the term instructional follows Remillard's (2018) distinction between *instructional* resources, which include "tools provided to, appropriated by, or generated by teachers to guide or support instruction," and *curriculum* resources, which refers to those that "attend to sequencing or mapping students' learning over a period of time" (p.70-71). Many instructional resources are components of curriculum resources, but they can also be sourced elsewhere.

2.1 Digital Instructional Resources and the Potential for Transformation

The potential for DIRs and tools to influence and possibly play a transforming role in aspects of teaching and learning is explored by Pepin et al. (2017) in a conceptual review framing research on digital curriculum resources in mathematics education. These authors, complemented by Ruthven's (2018) exemplars of instructional activity mediated by digital resources, define *transformation* as evidence of two types of shifts in standard practice: changes in what students (and teachers) are expected to do and changes in who interacts with whom. DIRs, they suggest, can be designed to allow students to explore, manipulate, and interact with visual representations of mathematics concepts in ways that promote exploration and inquiry, leading to student-generated inferences (Ruthven et al., 2009). Tools that facilitate

communication between students and visualization of students' mathematics work can lead to shifts from primarily teacher-student (T-S) or material-student (M-S) interactions to include more student-student (S-S) interactions (Pepin et al., 2017). In seeking to uncover possibilities for transformation of teaching and learning through the take up of DIRs, we consider these shifts, as well as others not proposed by these authors.

Pepin et al. (2017) conceptualize four learning spaces that intentionally designed DIRs could impact in transformative ways: a) the presentation space (how material and topics are presented to students); b) the problem space (types of problems students encounter and the range of ways they might solve them); c) the work space (tools and resources available to solve problems); and d) the navigational space (possible paths for progressing through the content). Additionally, Pepin et al. discuss features that impact how teachers monitor and assess student learning, which can lead to shifts in teachers' practices related to formative assessment and instruction. While the focus of our analysis is on teachers' use of DIRs and not the resources themselves, we lean on these spaces to identify dimensions of teaching and learning that might be impacted through their use.

Despite the conceptualized potential for transformation across these domains, Pepin et al. (2017) question whether most DIRs are designed with this aim in mind. Based on a review of commonly used DIRs, they argue that the potential to "transform the learning space is most amply manifest in the presentation space" (p. 651). With some exceptions, problem and work spaces remain similar to those provided by print textbooks, providing limited potential to support shifts in the nature of classroom interactions. Further, an analysis of 8 digital curriculum programs in the U.S. characterized six of them as "digitized versions of traditional textbooks" with "individual learning designs," which they found to emphasize rote learning and primarily T-S or M-S interactions (Choppin et al., 2014). Ruthven (2018) refers to such designs as "cautiously innovative." In contrast, citing Clark-Wilson (2010) and Ruthven et al. (2009), Ruthven (2018) suggests that digital resources that promote exploratory activity, S-S interactions, and teacher reports on student understanding are better positioned to support substantial shifts in classroom interactions.

2.2 Teachers as Key Mediators

As alluded to earlier, much of the research on teachers' use of DIRs is organized around particular tools or technologies, highlighting the potential impact of their design on teaching or classroom interactions. In this study, we take a teacher-centric approach, seeking to understand how teachers use DIRs in their daily practice. This perspective assumes that teachers are key mediators in the take-up and use of DIRs; as such, the potential for these resources to play a transformative role in mathematics teaching and learning is contingent on how teachers use them. Remillard (2005; 2018) conceptualizes teachers' curriculum use as a dynamic interplay between the teacher and the curriculum resource, viewing resource use as a participatory process, rather than one of passive implementation. As with print resources, teachers make use of DIRs in a variety of ways and are generally guided by their instructional goals and commitments (Clark-

Wilson, 2010; Murphy et al., 2014; Ruthven, 2018). In other words, while some DIRs *can* make possible new types of interactions between teachers, students, and mathematics, the incorporation of innovative DIRs does not ensure significant change.

The developing research on teachers' use of DIRs offers several framing concepts to describe this process. In a review of mathematics teachers' work and interactions with resources, both print and digital, Pepin, Gueudet, and Trouche (2013) highlight conceptual distinctions between terms used in the literature. A*doption* is typically used to refer to a curriculum program or textbook that has multiple components and is used, or modified, as a whole. *Integration* is more commonly used to refer to how DIRs are taken up. Among other things, integration usually refers to a process of incorporating individual digital components into one's regular practice. Pepin and colleagues also note that the term *appropriation* is also used to describe what teachers do when they take up DIRs and transform them for their purposes according to their agency and knowledge. These terms hint at the role teacher agency plays in take-up of DIRs.

We also take a context-specific approach, by exploring how teachers in different educational systems interpret innovations available to them. We believe that teachers' responses to these resources and explanations of the value they have in their mathematics teaching offer insight into practices and norms within each context (Hiebert et al., 2005; Tobin et al., 2009). Considering teachers' perceptions within and across cultural contexts, as well as the different types of access they have to DIRs, can add nuance to existing research, which tends to take a universal perspective. By asking teachers to describe their uses of DIRs and assuming that their explanations are reasonable, we seek to understand their reported practices within a cultural context.

3. Design and Methods

Our data come from interviews conducted during the 2017-18 school year as part of a larger study of elementary teachers' use of print and digital mathematics instructional resources in Belgium, Finland, Sweden, and the U.S. The selection of educational contexts represents the cultural backgrounds of the research team and allows us to leverage insider perspectives in our analysis. In Belgium, we focus on the Flemish Community, which is culturally and educationally distinct from the French and German-speaking communities. The research team is comprised of researchers who are cultural insiders in each context. English is the only language that all have in common.

To identify participants, we selected two elementary mathematics curriculum programs used in each context (detailed in Sect. 4.1). We identified a sample of 10 grade 1-6 teachers, 5 using each program, from schools in each context. Our aim was to hear a diversity of perspectives, without the intent of drawing a representative sample. Each teacher is understood as a case of a teacher from the particular educational context, using a selected primary

curriculum program. Teachers varied in years of experience (1-26 years) and the type and size of school they taught in.[2]

3.1 Key Contextual Features

In both Finland and Sweden, teachers have a high degree of autonomy over curriculum selection, teaching strategies, and student assessment. National core curricula guide teachers' overarching goals across 2-3-year grade-level bands; however, the objectives are broad. Teacher's guides within both contexts provide basic information about lesson goals, but teachers decide how to implement lessons. Teachers in Sweden are distinct in that they often incorporate several different curriculum programs in order to respond to individual learners' needs. Teachers in Finland, who enter the profession after extensive teacher education, tend to use a single curriculum program that they believe is in line with their pedagogical thinking (Hemmi & Ryve, 2015).

In Flanders and in the U.S., authority often resides at the school level or in groups of schools (districts in the U.S., umbrella organizations in Flanders). These organizations provide more specific goals for each grade level, and in the U.S. teacher's level of autonomy depends on the school and district. Teacher's guides in both contexts are more detailed and comprehensive than in Sweden or Finland, sometimes providing step-by-step instructions for teachers to follow. The U.S. is unique among the four contexts for its system of accountability, often resulting in teachers feeling pressure to cover required content and get all students to certain levels of mastery by the end of each academic year.

3.2 Data Collection and Analysis

This paper presents findings from two semi-structured interviews of the 39 teachers[3]. The one-hour, audio-recorded interviews, conducted in the teachers' primary language, addressed: the print, digital, and concrete instructional resources used by the teacher; the teacher's views on these resources; and the teacher's general beliefs about teaching and learning mathematics. They were conducted in person, typically in the teacher's classroom, and relevant artifacts were photographed. This approach reflects our goal of understanding teachers' instructional decision-making within and across contexts.

Once interviews were transcribed, insiders to each context summarized teachers' responses to each interview question in English in a spreadsheet, covering all 39 teachers grouped by context. Looking across this spreadsheet facilitated discussion of the data set within our cross-cultural team and allowed cultural insiders to add clarifying information. The full team discussed similarities and differences, identified themes, provided clarifications, and used the four learning spaces identified by Pepin et al. (2017) to consider the potential for transformation

[2] We did not use school type (public, private, free, etc.) as a selection criterion, as these types are not easily equated across contexts.

[3] One Finnish teacher did not complete the interviews.

of learning opportunities through the uses of DIRs described across the data set. Team members translated illustrative quotes into English or read auto-translated interview segments to deepen cross-contextual understanding of the data.

Through this iterative process, we identified several domains of teaching practice that served as sites for use of DIRs across all four contexts. We focused our analysis on two of them, teacher-led class instruction and student practice, because they involved distinctly different resources and practices. To analyze teachers' use of DIRs within each domain, we first identified and defined overarching patterns across the set of teachers and then created categories that allowed us to demarcate substantial differences in uses of DIRs. After tentatively placing teachers in each category, we reviewed the interviews and artifacts for confirming and disconfirming evidence. When placing teachers in categories (see Tables 2 and 3), we were cognizant of Clarke's (2013) "validity-comparability compromise" implicit in cross-cultural research: the need to balance context-specific knowledge with "analytical frame[s] that afford reasonable comparison" (p. 1856). We opted to favor cultural specificity by categorizing teachers in relation to others in their context, recognizing that this decision may sacrifice some validity of the dimension. The third domain of practice included in the findings, professional participation, emerged from our data as an area of teachers' professional work highly impacted by DIRs, but not often analyzed.

To supplement our understanding of teachers' reports, we analyzed characteristics of the main DIRs teachers mentioned using, giving the most attention to the student-facing platforms discussed in Section 4.3. We explored sample content, viewed demonstration videos, and read explanatory texts. We identified a set of common features, some of which overlapped with Choppin and colleagues' (2014) analysis, and then applied them to our analysis of all platforms. We categorize these features based on their purpose as defined by our own analysis as well as teachers' reflections.

4. Findings

The majority of teachers described using DIRs for some aspects of their mathematics teaching, but they did so to differing extents and to serve different purposes. Across all four contexts, we identified three major domains of teaching practice where many teachers reported making use of DIRs: a) class instruction, b) supporting student practice, and c) professional participation. The following sections present patterns we found in teachers' reported use of DIRs within each domain and their underlying reasons, highlighting cross-contextual similarities and differences. We draw on and add to the frameworks offered by Pepin et al. (2017) and Ruthven (2018) to consider the potential for DIRs to support transformation of teaching and learning spaces. We begin by briefly outlining available digital devices, hardware, and other resources in the four contexts.

4.1 Available Digital Devices and Resources

As indicated earlier, teachers were selected based on their use of one of two curriculum programs used in each context; one was established, having been used for a substantial period of time, and the other was newer to the context. The programs are listed, along with key characteristics and accompanying DIRs, in Table 1. All programs included a digital copy of the teacher's guide (static) and student textbook, five of which allowed student interaction. Most included slides teachers could use during class instruction. Several curriculum developers had partnerships with digital learning platforms, such as Bingel (SW/FL) or Zearn (US), which extended the digital offering aligned with the program.

Table 1.
Titles and Descriptions of Curriculum Programs

Country	Program Title (abbr.)	Teachers	Program Characteristics	Digital instructional resources available
Finland (FN)	*Tuhattaituri* (TT)	FN 1-5	Established, mainstream	Teacher's guide, interactive student textbook with answer correction, slides, videos
	YyKaaKoo - NeeViiKuu (YN)	FN 6-9	New, alternative	Teacher's guide, interactive student textbook with answer correction
Flanders (FL)	*Kompas* (KP)	FL 1-5	Established, mainstream	Teacher's guide, static student textbook, slides, practice problems on CD with answer correction
	Nieuwe Pluspunt (NP)	FL 6-10	New, alternative	Teacher's guide, interactive student textbook with answer correction, slides, videos
Sweden (SW)	*Favorit Matematik* (FM)	SW 1-5	New, alternative, modified from TT (FN)	Teacher's guide, interactive student textbook, slides, videos, teacher learning videos
	Matte Direkt (MD)	SW 6-10	Established, mainstream	Teacher's guide, interactive student textbook with answer correction
United States (US)	*Everyday Mathematics* (EM)	US 1-5	Established, alternative	Teacher's guide, interactive student textbook; slides, student mathematics games, teacher learning videos
	Eureka (EK)	US 6-10	New, alternative, open access	Teacher's guide, static student textbook, slides, teacher learning videos

Based on teachers' reports and triangulated by the knowledge of members of the research team, the hardware available in classrooms was fairly comparable across the four contexts. Almost all classrooms were equipped with interactive whiteboards or digiboards (referred to as digiboard going forward) and projectors. In addition, all Finnish classrooms were equipped with document cameras, as were a few Swedish classrooms. The majority of classrooms had access to computers or tablets for students to use on a regular basis. While few schools supplied laptops for each student, most had sets of computers or other devices that were shared by students in a single classroom or across multiple classrooms. In a few cases, particularly in Finland and Sweden, teachers described missing or poorly working devices or unreliable internet.

4.2 Class Instruction

All teachers described spending some amount of time during their mathematics lessons presenting material to the class and discussing concepts. Although the length of time and sequence in the lesson varied, they shared common features: typically whole-class, teacher-led instruction was followed by, or intermixed with, sustained periods of teacher-mediated, independent or small group practice. The majority of teachers in our sample (31 of 39) reported leveraging classroom technologies and presentation software during class instruction. Based on the descriptions and lesson artifacts they provided, we identified two distinct approaches to incorporating DIRs into class instruction. The majority of teachers across all four contexts described using DIRs to enhance existing practices and teaching approaches common to the context. We describe this approach as *appropriating* DIRs into existing purposes (Pepin et al., 2013). A smaller number of teachers also described using DIRs in ways that were *adaptive*. These teachers leveraged particular affordances of DIRs to extend the nature of classroom interactions in innovative ways. In each context, a few teachers reported minimal or no use of DIRs during class instruction. These groupings are summarized in Table 2 and described in more detail below.

Table 2

Approaches to Using DIRs During Class Instruction

	Finland	**Flanders**	**Sweden**	**U.S.**
Adaptive		FL3, FL5	SW8, SW9, SW10	US6
Appropriating	FN1, FN2, FN5, FN7, FN8, FN9	FL1, FL2, FL4, FL7, FL8, FL10	SW1, SW2, SW3, SW4, SW7	US1, US2, US3, US5, US7, US8, US9, US10
Rare or Never	FN3, FN4, FN6	FL6, FL9	SW5, SW6	US4

Note: Each identifier refers to a unique teacher from the context.

4.2.1 Appropriating DIRs into class instruction

As shown in Table 2, the majority of teachers in each context and overall reported using DIRs during class instruction by appropriating them into typical instructional interactions where knowledge is passed from teacher to students. Teachers in this category generally reported using DIRs to make instruction more effective or engaging for students. Appropriating practices involved using classroom technologies to project media for the entire class to see and interact with. Most teachers projected static images from the student textbook; some also created or modified slide presentations, often incorporating animations or videos into them. Since most classrooms had digiboards, several teachers reported using digital manipulatives that students could interact with. In addition to using the resources that came with their curriculum materials,

teachers in all four contexts reported searching online or going to known websites for teachers to find images, videos, or activities to make presentations more engaging or visual. As the following examples illustrate, the uses of DIRs in this category were restricted to impacting what Pepin et al. (2017) label as the presentation space, referring to the "range of tools and media available to present topics" to students (p. 649). All six teachers categorized as using DIRs in adaptive ways (discussed in the next section) also reported appropriating practices.

Swedish teachers described using a variety of DIRs during class instruction. Teachers using *FM* used digital slides that accompanied the program, while several using *MD* created their own. Several *FM* teachers described launching lessons with "frame stories," which present a mathematics task, along with digital manipulatives, that the class could work on together. Similarly, all but one U.S. teacher described using or creating digital presentations to guide students through instruction. Many used presentations from their curriculum program, which contained a combination of static and dynamic images, but often modified them to suit students' needs. Finnish teachers described using DIRs during class instruction less regularly than their counterparts in the other contexts, but they reported similar types of uses as those from Sweden and the U.S., including projecting the students' textbook pages to guide their instruction, showing animated illustrations and digital manipulatives the students could interact with. In contrast, the six Flemish teachers in this category reported projecting completed student textbook pages during class review of answers to support discussion of the problems.

While possibly falling short of the criterion for transformation set out by Pepin et al. (2017), the role that incorporating DIRs into class instruction played in these teachers' practices should not be underestimated. Teachers in this group saw many benefits of DIRs. They told us that projecting material enhanced the instructional component of their lessons by making the material "more visual" and allowing the class to go through it together. One Swedish teacher explained, "I usually start with the whiteboard or projector, so we can go through it together" (SW4). Teachers who used digital manipulatives or other dynamic presentations on digiboards appreciated the potential for "hands-on" interaction. Those who used videos or animated presentations indicated that they illustrated the mathematics concepts in ways that students found accessible. The majority of teachers in this group also indicated that students found digital presentations more "motivating" and "engaging." A grade 6 teacher from the U.S. illustrated these perspectives when describing her view of the videos she used during instruction: "They show visuals, they show models...[and] make it entertaining for them. They [the videos] use the same strategies and tools as *Eureka*" (US8). The idea that DIRs were better if they aligned with their primary curriculum program was a priority expressed by U.S. teachers alone.

Finnish teachers, in general, expressed more caution than the others about the limitations of available DIRs. These concerns appeared to stem from their positions on learning and the features of available educational materials. Several Finnish teachers argued that students needed to interact with physical material, including paper and pencil, in order to "activate" learning. Finnish teachers were also less inclined to select resources for engagement or fun purposes.

4.2.2 *Adaptive uses of DIRs*

We categorized six teachers' use of DIRs during class instruction as adaptive (see Table 2), because they deployed DIRs in ways that contributed to shifts in classroom work and interactions between the teachers, students, and mathematics in ways that were distinct for the context. A number of researchers (Clark-Wilson, 2010; Pepin et al., 2017; Ruthven, 2018) assert that digital resources that facilitate communication among students and make visible students' mathematics work can support adaptations of typical classroom interactions between teacher, students, and resources. Although there was substantial variation across the six teachers we placed in this category, all described classroom modes of interaction other than the T→ S mode, most common during class instruction in each context.

Three Swedish teachers, for example, described using an instructional model promoted in this region called "EPA," (enskilt-par-alla or individual-pair-all). Teachers present students with a problem to work on, first individually and then in pairs. Then, using a tablet and projector, students share their solutions with the class in order to generate a discussion about the work. A grade 5 teacher explained:

> We discuss these solutions by asking, for instance: How did this person think it through? ... I photograph some of the results every time. They [the students] love this. They all want to contribute with their solutions and to be posted on the board. (SW8)

The three Swedish teachers attributed their use of the EPA model to dissatisfaction with resources provided by *MD* and a desire to include more collaborative student learning than is typical in Swedish instruction. SW10 also indicated several additional benefits, including students learning from peers, students using language to express their ideas, and quickly assessing student understanding.

The one U.S. teacher in this category described using his classroom laptop set and Zearn, an online student-facing platform (described in Section 4.3), to create a modified flipped-classroom, which shifted how he and students interacted with mathematics. Zearn includes interactive instructional videos, practice problems, and scaffolds. Advanced students spent the first half of math class being introduced to new content individually on Zearn and completing basic problems, which he monitored through the Zearn dashboard, while working with the other group. When the two groups switched, he explained that the first group was ready to work on "harder tasks" together, while the other group completed basic problems on Zearn. The teacher monitored both groups of students by checking for alerts on the Zearn platforms. The teacher explained that Zearn was like having "a second teacher in the room" (US6), allowing him to provide two groups of students tailored learning experiences at an appropriate level.

The two Flemish teachers in this category used digiboard technologies and dynamic software to shift students' interactions with mathematics through technology. FL5 regularly combined a number of DIRs found online to engage students in interacting with mathematics concepts and digital manipulatives. In an interview, she stated, "If I have no computer or the internet is down, I cannot teach." While somewhat less ambitious in her use of DIRs, FL3 also stood out to us as distinct from the other Flemish teachers. She described the power of dynamic

software and her digiboard to make mathematical concepts more accessible to students. She explained. "I can't work with 3D figures on my chalkboard." With the 3-D software, a polyhedron can be unfolded into its net and you "can turn it around with your mouse."

4.2.3 *No added value*

Eight of the 39 teachers we interviewed (1 to 3 from each region) rarely or never used DIRs during class instruction. At least one teacher from each European context expressed that they preferred chalkboards and paper textbooks and did not see DIRs adding value to their teaching. Other teachers, including one from Finland, Sweden, and the U.S., cited a philosophical mismatch between the approaches promoted by the resources they had and their views about young children's learning, in which interactions with concrete materials and one another should be central.

4.2.4 DIRs and transformation during class instruction

Across the four contexts, teacher-led instruction, where mathematical knowledge passes from the teacher to students, was a predominant classroom format. Further, teachers' primary curriculum programs figured significantly in their lessons. The majority of teachers in our sample who used DIRs during class instruction did so by appropriating them into this established classroom format, primarily impacting the presentation space (Pepin et al., 2017). This pattern is reminiscent of Ruthven's (2018) observation that "digital resources are often, at least initially, assimilated to established patterns of instructional activity" (p. 262).

Ruthven (2018) also asserts that, depending on their affordances DIRs, "have the potential to reorganise such activity in significant ways," potentially extending their impact (p. 262). Looking specifically at the six teachers we identified as using DIRs in adaptive ways, it is evident that specific DIRs played a role in extending the types of interactions possible during class instruction, but they did not necessarily instigate these shifts. We see a nuanced relationship between the teacher and resources, where teachers leveraged DIRs to accomplish an instructional goal, while the affordances of particular DIRs helped the teachers imagine different possibilities. Importantly, this level of use of DIRs during class instruction was the exception, not the norm, in our data and the particular resources in question varied considerably.

4.3 Supporting Student Practice

Almost all teachers in our sample spoke to the importance of independent student practice with mathematics skills. The majority of teachers (29 of 39) reported using online platforms that students interacted with directly during math class, or other designated times, in order to practice fluency skills, solve problems, or play mathematical games. We labeled this class of resources online student-facing platforms (OSFP). Pepin et al. (2017) suggest that these platforms can potentially impact the problem space (types of problems and range of ways to solve them) and the work space (tools and resources available to solve problem) by increasing problem solving, communication between students, and creative approaches to learning, but caution that they are often designed to replicate the status quo. Pepin et al. (2017) also suggest

potential transformation of the navigation space and data reports as a tool for extending formative assessment.

In order to situate the patterns of OSFP use in our data, we first summarize our analysis of available platforms in each context. We then discuss how these features were related to teachers' patterns of use and how teachers reflected on their decisions about using them.

4.3.1 Features of online platforms

The teachers in our study collectively used 28 student-facing platforms (see Appendix). These platforms ranged substantially in their coverage of and approach to mathematics content, as well as their resources for teachers and students. We identified three categories of features of student-facing platforms that helped us to understand their potential to transform learning spaces or teachers' work: a) student guidance, b) support for customization, and c) depth of available content. Each category includes several features likely to alter or extend students' learning experiences, although these shifts appear to be limited to interactions between students and the resource with the aim of accomplishing a personalized learning experience.

The *student guidance* features include automated feedback and instructional support. These features seek to replicate the explanations or feedback provided by a teacher or textbook, but are often designed to be adaptive and responsive to individual students' activity. Immediate feedback through hints and explanations, in response to student answers, for example, provide just-in-time support. Additionally, many of the platforms offer instructional videos or animated step-by-step explanations of content, allowing students to receive tailored, individualized instruction. While reproducing the status quo, as Pepin et al. (2017) suggest, and reducing student-student interaction, these features are likely to impact the work space (the tools and resources available to solve problems) through adaptive scaffolding.

The *customizing* features support the creation of individualized learning pathways for students through content and allow teachers to monitor student progress. Many platforms either provide embedded assessments and then automatically assign students to particular problems based on the results or allow the teacher to assign students specific tasks within the platform. These features impact the navigation space, or the possible paths for progressing through the content (Pepin et al., 2017). Most platforms also generate teacher reports, which Pepin and colleagues suggest have the potential to deepen and extend the role of formative assessment in mathematics instruction by providing teachers additional information on student understanding that can guide instructional decision-making.

The category we call *depth and focus of content* refers to the mathematics content included in the OSFP and considers the extent of alignment to the school curriculum. Some platforms, for example, were produced by or aligned with the primary textbook or curriculum program; others followed the official curriculum in the context; others were designed to address a specific set of skills. Teachers frequently mentioned the content focus as influential in their decisions whether or not to use these resources.

4.3.2 Platforms by Context

Teachers in the U.S. reported making substantial use of student-facing platforms with 9 teachers using a total of 9 platforms. In general, U.S. platforms made comprehensive use of the features described above, with professional design quality and usability. The majority of the platforms (7) offered full curriculum coverage and followed the *Common Core State Standards for Mathematics*. Five of the platforms included robust student guidance features that provided complex tasks and visual models. All allowed for some type of support for teacher customization of tasks through adaptive or manual means and provided reports for teachers indicating students' progress.

Seven of the Swedish teachers described using a total of 12 different student-facing platforms. As in the U.S., 4 of these platforms were developed to cover the National Mathematics Curriculum. These platforms featured student guidance through instructional videos or worked examples. Four of the 12 platforms included features with monitoring and individualized assignment capacities to support teacher customization. The majority (7) of platforms were apps or websites that focused on skills practice.

Seven Finnish teachers reported using a total of 7 programs. When compared to Sweden and the U.S., Finnish platforms were less comprehensive, supporting limited content, or seemed to either replicate the class lessons without adding technology-enabled features or did not match the timing of the textbook. Three other platforms focused on skills practice, some with limited opportunities for customization. One unusual platform, Vektor, was designed to support students in developing mathematical thinking through creative mathematical games.

Flemish teachers reported the lowest use of OSFPs, with 6 teachers using a total of 3 platforms, two of which focused primarily on skills practice. All 3 platforms offered some customization through adaptive difficulty and reports for teachers. Only 1 platform, Bingel, provided student guidance and included the full range of curriculum topics presented in the order of the *Nieuwe Pluspunt (NP)* curriculum.

4.3.3 Patterns of use

Across the 39 teachers, we identified four overarching categories of use of OSFPs, defined by the frequency and intent with which teachers incorporated them into their practice: *extensive, integral, supplemental,* and *rare or never* (see Table 3). Below, we describe each category, along with the range and variation of practices within each. We also discuss patterns in how teachers in each category viewed OSFPs, along with platform features and contextual factors that appeared to influence teachers' use of online platforms to support student learning.

Table 3

Categories of Use of OSFPs

Categories of Use (# of platforms)	**Finland** (7)	**Flanders** (3)	**Sweden** (12)	**U.S.** (9)
Extensive				US1, US2, US5, US6
Integral	FN1, FN3	FL8	SW1, SW3, SW4, SW9	US3, US7, US8, US9, US10
Supplemental	FN2, FN4, FN5, FN7, FN9	FL5, FL3, FL4, FL6, FL7	SW7, SW8, SW10	
Rare or Never	FN6, FN8	FL1, FL2, FL9, FL10	SW2, SW5, SW6	US4

Note: Each identifier refers to a unique teacher from the context.

4.3.3.1 Extensive use

Only U.S. teachers (4 of 10) reported *extensive* use of OSFPs, incorporating multiple programs or multiple features of student-facing platforms to extend student practice, during class time and from home. Teachers in this category described using platforms several days of the week or more, sometimes for entire supplemental class periods, to provide comprehensive student practice. For example, US5 used games and manipulatives associated with *ConnectEd,* the student facing platform from *EM,* but also assigned homework and additional practice on IXL, because it allowed her to track students' progress. Since the majority of online platforms used by U.S. teachers reflect the content students are expected to master for annual high-stakes tests, it is not surprising that most U.S. teachers viewed OSFPs as effective tools to provide students with necessary skill practice, while allowing them to monitor student progress. In several cases, teachers were required to use particular OSFPs by their school.

4.3.3.2 Integral use

Teachers who reported *integral* use of OSFPs described relying on them to help students learn specific mathematics skills. The frequency of use varied, but for all teachers, online platforms constituted a key resource for student learning and skill development. Many teachers in this category reflected on how features of the platforms for both student guidance and customization, as well as the depth of content covered, helped them individualize practice for specific students.

As shown in Table 3, Swedish and U.S. teachers dominated this category. Like their colleagues categorized as extensive, U.S. teachers in this group felt OSFPs allowed them to assess and monitor students' progress toward specific standards and assign additional practice to

specific students as needed. In an interview, US8 demonstrated her use of the platform dashboard and explained: "It shows they got 65 percent of questions right. So, I can assign them problems that literally cater to exactly where they need to be doing work or relearning a skill." Similarly, the Swedish teachers explained that using OSFPs allowed them to provide students with targeted support in ways that they found engaging, fun, or simply different or new. SW9 valued Bingel's support for customization and monitoring student progress: "I can see, these students have done it, these have 9 of 10 right, these students have 4 of 7. So, I can see exactly, problem by problem, what they have trouble with."

Only one Flemish teacher used platforms to customize students' learning. FL8 reflected on how the features for customization transformed his ability to differentiate: "You can put in student scores and then you get personalized exercises, both online and you can print them out as well. That, I think, is very handy. Before, one had to cut and paste a lot and search yourself, whereas nowadays, this gets done for you."

The two Finnish teachers who reported integral use of platforms described the depth and quality of content as motivations for their use. One explained, "[ViLLE has] quite a lot of game-like exercises but it's not just entertaining, possibly because it is developed by university people, so I feel that it covers more and maybe of higher quality than the ones that are produced by a publishing company" (FN1).

4.3.3.3 Supplemental use

The majority of teachers in European contexts reported use of OSFPs as *supplemental*. While teachers in this category also reported valuing OSFPs for their ability to individualize student learning, they reported using them only as needed. Some teachers described providing students the option of whether to use the OSFPs as a change of pace from completing textbook pages. Though some teachers mentioned monitoring student progress, few of the teachers in this category reported using features for student guidance or more robust customization of student learning, although a number of platforms in each context included these features.

The three Swedish teachers discussed these resources as options for students to log on and practice if there was extra time. Several teachers indicated that they were a source of extra practice that was more fun than completing problems in the textbook. In Flanders, a grade 6 teacher thought students found using Bingel "more interesting" than the regular tasks (FL4). While Finnish teachers had students use these platforms to practice certain computational skills, the majority of teachers (5) responded to these options cautiously as occasional supplements or for optional homework. They valued work with physical materials and the paper textbook and did not see online practice as a replacement. FN5 asserted, "I still think using a printed textbook is a good thing." While these teachers viewed OSFPs as useful and reported students finding them entertaining, the teachers in this category did not view the platforms as an essential resource.

4.3.3.4 Little to no use

Across all contexts, a portion of teachers reported *rarely or never* using OSFPs. Teachers in this category often viewed work with manipulatives or other concrete materials as more effective means for student learning than digital platforms. Teachers' aversion to using these resources sometimes stemmed from technical problems, a lack of time or motivation to explore available DIRs, or teachers' feeling that computerized platforms did not contribute anything additional to students' learning experience.

One Finnish teacher expressed concern that students might be distracted by the entertaining components. This grade 4 teacher explained: "Children are often enthusiastic about any digital material in the beginning, but they don't think about the goals, but the entertainment" (FN6). Instead, she felt working with concrete materials was more beneficial for young children. The 1 U.S. teacher who did not report using any platforms expressed a similar sentiment, saying that her students "would rather play a [mathematical] game with a friend...And I'm okay with that" (US4). One Swedish teacher (SW6) was unable to use any digital platforms because all of the schools' computers had been stolen, while the other Swedish teacher felt that "it works well as it is" without using platforms (SW5). Similarly, a Flemish teacher felt more inclined toward traditional practices, saying, "no, I'm not a computer hero. I'm really old-fashioned" (FL10).

4.3.4 OSFPs and transformation

While providing opportunities for students to practice mathematics skills and develop fluency was a priority for almost all teachers in our sample, we found substantial cross-cultural variation in their views of how OSFPs might be leveraged to support student practice. Our analysis suggests that the general patterns of use we found reflect an intersection of context-specific educational traditions, teachers' own beliefs, and the quality and suitability of OSFPs for their purposes. More U.S. and Swedish teachers viewed OSFPs as appropriate for supporting student practice, reflecting both the greater availability of robust platforms in these contexts (at least for our sample) and contextual factors that made these resources desirable. In the U.S., most online platforms reflect the content students are expected to master for annual high-stakes tests, making them effective mechanisms for monitoring students' progress within a stringent system of accountability. In Sweden, teachers' reported use of a variety of platforms, often for different students, aligns with the Swedish norm of responsiveness and individualization in teaching (Hemmi & Ryve, 2015).

In Finland and Flanders, teachers reported fewer available platforms that align with the curriculum or support their learning goals, a claim confirmed by our analysis of the platforms. At the same time, teachers in both Finland and Flanders, as well as several in Sweden, expressed a preference for paper and pencil and concrete materials, even when using OSFPs that had more capabilities. It is worth noting that a quarter of the teachers in our sample, including at least one from each context, expressed strong skepticism of having students use OSFPs, primarily on philosophical grounds.

The fact that three quarters of the teachers in our sample used OSFPs, almost half doing so with some regularity and using multiple features, suggests that these platforms may be an

increasing ingredient in students' mathematics learning experiences. In this sense, OSFPs *are* transforming teaching and learning. Identifying the nature of this transformation is more complex, as it depends on the features of the platforms and how teachers use them. We see a number of student guidance features, including adaptive scaffolding and corrective explanations in response to student errors, as having the potential to extend the work space by deepening the interactions between learners and the resource as they solve problems. Customization features allow this type of guidance to occur as needed, once the student has attempted to solve the problem. Further, several customization features have the potential to transform teachers' work by providing them with reports on student progress and errors and enabling the possibility to individualize students' learning pathways. Others have offered defensible critiques of OSFPs for replicating status quo instructional practices and reducing opportunities for student-student interactions (Choppin et al., 2014; Pepin et al., 2017). There is some evidence, however, that teachers can leverage OSFPs to support tailored, individualized learning of basic mathematics skills, in conjunction with engaging a class of students in collaborative problem solving, as illustrated by US6 in Section 4.2, as well as Murphy et al. (2014).

4.4 Professional Participation

Teachers in Flanders, Sweden, and the U.S., described using online resources in ways that increase teacher-teacher connectivity, such as collaborating with other teachers and engaging in online professional learning. Although these include non-instructional aspects of teachers' work, we believe they may underline important professional shifts that have the potential to transform teachers' instructional approaches and incorporation of DIRs. As Ruthven (2018) indicates, the potential for transformation through the use of DIRs often differs based on teachers' use. Increased connectivity through the use of websites provides teachers with more opportunity for professional learning and sharing of ideas and instructional strategies. Understanding this type of use of DIRs was not part of the original scope of this study, however it emerged as a theme across several contexts. Because we did not ask explicitly about this type of use in the interviews, we report only instances that teachers happened to mention; thus, it is likely they are underreported in our findings.

File sharing with colleagues through online repositories was the most prominent way that teachers used DIRs for collaboration. All 10 U.S. teachers and half of the Swedish teachers shared lesson plans, assessments, and other activities through cloud-based platforms within their schools or districts. This type of file sharing was not mentioned by Finnish teachers and was only mentioned by 1 Flemish teacher, who maintained an extensive collection of Dropbox folders containing lesson plans that she had created and made available to her grade-level colleagues.

A smaller proportion of teachers, mostly from Sweden and the U.S., described using social media sites and online lesson repositories to collaborate with teachers well beyond the boundaries of their own schools. Four Swedish teachers said they regularly visited Facebook and Lektion.se to share ideas and resources with other teachers. Five of the U.S. teachers also used educational sites to find resources and ideas that fit with their lessons. US10 describes using

EMBARC, a teacher-created platform with myriad resources for teachers using EK materials: "It's the be all end all of having what you need right there in front of you." We see the use of these sites as significant because it represents exchanges made among teachers and a disruption of the siloed nature of teaching.

In three of the contexts, teachers also reported using DIRs to enhance their own professional learning. Half of the Swedish and U.S. teachers reported watching videos designed to educate teachers about mathematics concepts or pedagogical approaches. In the case of the U.S., some videos were associated with their curriculum programs, but most found videos created by other teachers on YouTube or other websites. They reported watching them to understand the intention of the lesson and improve their teaching. One Flemish teacher reported changing her instructional approach for a lesson after viewing a YouTube video recommended by a colleague.

The expansion of connectivity through social media and other websites offers teachers more frequent opportunities for professional development and collaboration. Increased exposure to these types of DIRs is important, as participation in professional collaboration can influence both the nature of teachers' work and the resources they have access to.

5. Discussion

Digital instructional resources are expanding rapidly in their capabilities and availability around the world; many anticipate that these innovations will spark transformation of teaching and learning by shifting the nature of classroom interactions and opening up new learning spaces (Clark-Wilson, 2010; Pepin et al., 2017; Ruthven, 2018). In this study, we seek to expand understanding of the potential (and limitations) for DIRs to support transformation in mathematics teaching and learning by taking a teacher-centric approach and by considering the role that cultural context plays in their use. This focus is informed by a view that teaching is situated within an educational system and cultural traditions (Stigler & Hiebert, 1999), which serve as powerful filters for how resources are taken up (Koljonen, 2020). The transformative potential of DIRs is thus dependent on teachers' design decisions and the particular context.

In this section, we return to our research questions to extend current understanding of the ways DIRs might support transformation of teaching and learning, especially among elementary teachers. We first synthesize the patterns we identified in how teachers reported using DIRs across the four contexts. We then look across our data to consider possible new opportunities.

The majority of teachers in our sample readily used DIRs during class instruction and to support student practice, doing so by selectively integrating them into their teaching to meet their instructional goals, according to their preferences. In general, teachers looked to their primary curriculum program (along with national or local curriculum frameworks) to guide their mathematics teaching and, thus, selected DIRs that accompanied or complemented them, or filled gaps they identified. This finding reflects Pepin et al.'s (2013) notion that "an essential condition" for teachers' adoption of DIRs is their "potential for integration/inclusion into the

teacher's 'normal' practice" (p. 934). Our findings suggest that the potential for integration might also be a limitation. As shown in section 4.2, when appropriating DIRs into their teaching, few teachers did so in ways that transformed typical learning spaces.

At the same time, three quarters of the teachers in our study reported using DIRs for a variety of reasons and reported that their capabilities enhanced their 'normal' teaching practices, in both small and substantial ways. Our findings offer insight into factors likely to influence what DIRs teachers choose to integrate and how they do so. Following Pepin and colleagues (2013), we see integration as a necessary condition for opening up transformative opportunities. By looking more closely at teachers' uses of DIRs within the three domains of teaching discussed in the findings, as well as contextual factors that influenced them, we speculate on potential levers that might support such opportunities.

The first lever, illustrated by the 6 teachers who used DIRs during class instruction in adaptive ways, builds on existing research that shows how the design of resources matter. DIRs that promote exploration, interactions between students, and provide teachers insight into student understanding have the potential to support substantial shifts in classroom interactions (Clark-Wilson, 2010; Ruthven, 2018). In our data, teachers used DIRs to extend typical classroom interactions when the resources they had access to helped them consider new instructional possibilities that align with their goals. This lever underscores the critical interaction between teachers' instructional goals and the affordances of resources as they consider how they will take-up new DIRs.

A second lever that emerged from our findings is the characteristics and needs of the context, which frame the challenges and opportunities teachers confront and how they might use resources to address them. For example, across all three domains of teaching, we found that more U.S. and Swedish teachers were positively disposed toward using a variety of DIRs in sustained ways. This pattern was especially notable in the use of OSFPs, where 9 U.S. and 4 Swedish teachers reported extensive or integral use of these platforms. As described previously, teachers in both contexts viewed OSFPs as effective and robust tools to help them address needs and priorities of high value in the context.

The final lever we see in our data is professional engagement likely to introduce teachers to new resources, ideas, and instructional routines. A number of teachers in our sample reported using the internet to find resources and as a source of collaboration and professional development. This aspect of teachers' professional activity has drastically changed through the expansion of social media and the internet. In addition to sharing resources and ideas with colleagues locally, teachers are increasingly engaging with communities of teachers at a national level (van Bommel et al., 2020). We hypothesize that this lever has the potential to transform the nature of and ways teachers participate in their own professional learning (Tour, 2017). Further, to the extent that their personal learning networks include representations and discussion of other classrooms, teaching practices, and resources, they can be introduced to novel instructional routines and DIRs.

6. Conclusion and Next Steps

Despite the transformative potential of many DIRs, our findings suggest that efforts to use innovative DIRs to stimulate instructional change need to begin with a deep understanding of teachers' current practices, their goals, and the contextual structures in which they are situated. By many measures, we found few instances in which teachers were using DIRs in transformative ways. We did find that teachers in our study were positively disposed toward incorporating DIRs that aligned with their goals and enhanced or extended their work. We see this openness as a starting place for designing and introducing DIRs that have both integrative and transformative potential. Future research that considers elementary teachers' uses of DIRs over several years would be well positioned to explore how use of such resources evolves over time.

We were also struck by the substantial use of online student-facing platforms (OSFPs) across all four contexts to support individual student practice. Although their use varied, three quarters of the teachers in our sample reported using these resources and half did so with regularity. It is evident that, at least in some contexts, OSFPs *are* transforming students' learning experiences, potentially in directions other than those imagined by Pepin and colleagues (2017). Further, many of the OSFPs teachers used were sourced from outside of their primary curriculum program. (See Appendix A.) It is likely that the availability and capabilities of these platforms will continue to expand and influence students' mathematics learning experiences. More research is needed on the uses of these platforms, their design, and impacts.

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Appendix A

Online Student Facing Platforms

Region	DIR	Student Guidance	Customization	Content Description
FI	TT online	Textbook	Levels of difficulty	Curriculum Program
	YN online	Textbook	None	Curriculum Program
	Bingel	Videos	Adaptive, Task assignment & reports	Aligned to National Core Curriculum
	Ville	None	Adaptive, Task assignment & reports	Skills Practice
	10Monkeys	None	Reports	Skills Practice
	Ekapeli	Modeling	Adaptive learning path	Skills Practice
	Vektor	None	None	Cognitive Development
FL	Bingel	Videos	Adaptive, Task assignment & reports	Aligned with NP
	Gynzy	None	Adaptive, Task assignment & reports	Skills Practice
	Ambrasoft	None	Adaptive, Task assignment & reports	Skills Practice
SW	FM online	Textbook	Levels of difficulty	Curriculum Program
	Bingel	Videos	Adaptive, Task assignment & reports	Aligned with MD
	Edqu.se	Videos, feedback on errors	Task assignment/creation, reports (with subscription)	Aligned to National Core Curriculum
	Studi.se	Videos	None	Aligned to National Core Curriculum
	Nomp	None	Task assignment/creation, reports (with subscription)	Aligned to National Core Curriculum
	Multi	None	Adaptive	Skills Practice
	King of Math	None	Adaptive	Skills Practice
	Elevspel	None	None	Skills Practice
	Klockgården	None	None	Skills Practice
	Gruvan	None	None	Skills Practice
	Affären	None	None	Skills Practice
	10Monkeys	None	Reports	Skills Practice

US	EM: ConnectEd	Interactive textbook	None	Curriculum Program
	Zearn	Videos, hints, scaffolded support	Reports	Aligned with EK
	Compass Pathblazer2	Hints, explanations	Learning path, task assignment	Aligned with CCSS
	First in Math	Explanations	Adaptive, task assignment	Aligned with CCSS
	IXL	Explanations	Adaptive, task assignment & reports (with subscription)	Aligned with CCSS
	Study Island	Videos, explanations	Adaptive, task assignment & reports	Aligned with CCSS
	Dreambox	None	Learning path, reports	Aligned with CCSS
	SumDog	None	Reports	Skills Practice
	BigBrainz	None	Reports	Skills Practice